Polarization Control with Liquid Crystals

Liquid Crystal Variable Retarders are solid state, real-time, continuously tunable waveplates. Nematic liquid crystals are birefringent materials whose effective birefringence can be changed by varying an applied voltage.

Meadowlark Optics Liquid Crystal Retarders are constructed using precision polished, optically flat fused silica windows spaced a few microns apart. The cavity is filled with nematic liquid crystal material and sealed. This assembly ensures excellent transmitted wavefront quality and low beam deviation required for many demanding applications.

The long axis of the liquid crystal molecules defines the extraordinary (or slow) index. With no voltage present, the molecules lie parallel to the windows and maximum retardance is obtained. When voltage is applied across the liquid crystal layer, the molecules tip toward the direction of the applied electric field. As voltage increases, the effective birefringence decreases, causing a reduction in retardance. See Figure 4.6.

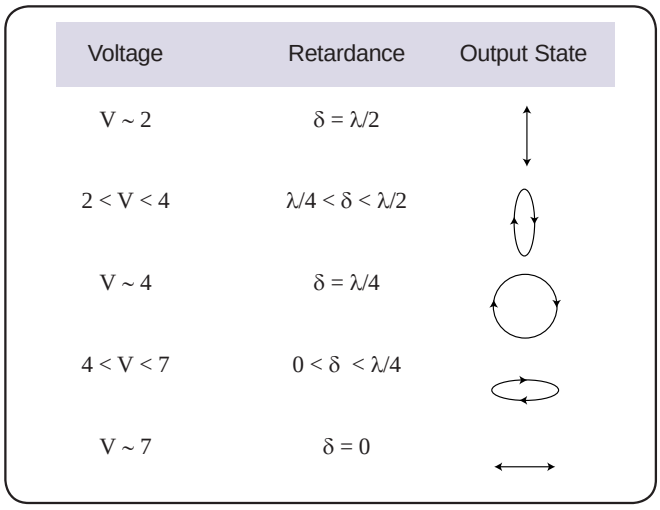


Fig. 4-1 Output polarization forms for different retardance values of a compensated variable retarder with horizontal linearly polarized input

Retardances greater than half-wave can be achieved by using high birefringent materials and/or increased liquid crystal layer thickness. Birefringence of liquid crystal materials decreases at longer wavelengths, requiring proper evaluation and design for optimum performance.

Meadowlark Optics Liquid Crystal Variable Retarders are used throughout the visible and near infrared region. While these liquid crystal retarders are affected by temperature and wavelength changes, they can be calibrated to accommodate those differences. The resulting Variable Retarder is versatile across a considerable thermal environment and significant wavelength range.

Liquid crystal retarders can offer outstanding performance over large incidence angles. Material type, cavity thickness and especially operating voltage play a large role in determining the acceptable input angle.

Phase control or modulation is possible for light linearly polarized 45° to the fast axis. Electrical control of the effective extraordinary index allows precision tuning of an optical phase delay in the propagating beam.

Liquid Crystal Variable Retarders

Meadowlark Optics Liquid Crystal Variable Retarders provide precise solid-state retardance tunability. These true zero-order devices are precision engineered, offering excellent performance in the visible to near infrared wavelength ranges. When combined with other optical components, our Liquid Crystal Variable Retarders produce electrically controllable attenuation, linear polarization rotation, or phase modulation.

Continuous tuning of retarders over a broad wavelength range is required for many applications. This added versatility makes real-time polarization conversion possible with a single Liquid Crystal Variable Retarder and electronic controller. Figure 4-1 shows a variety of output polarization forms achieved with a single device. Pure phase modulation is accomplished by aligning the optic axis of the liquid crystal retarder parallel to a linearly polarized input beam.

Variable attenuators with no mechanical rotation are configured by placing a Liquid Crystal Variable Retarder between crossed polarizers. Full 180° linear polarization rotation can easily be achieved by combining the Liquid Crystal Variable Retarder with a fixed quarter waveplate.

Spatial Light Modulators consist of individually controllable pixels. These devices are used in a variety of intensity and/or phase control applications where spatial variation is required. Please refer to the Spatial Light Modulator section for details and specifications on these innovative products.

A Liquid Crystal Variable Retarder is the fundamental component used in the following devices and systems.

- **Variable Attenuators and Rotators**
- **Variable Beamsplitters**
- **Spatial Light Modulators**
- **Non-Mechanical Shutters**
- **Beam Steerers**
- **Optical Compensators**
- **Polarimeters**
- **Tunable Filters**

NEW from Meadowlark Optics
Swift Liquid Crystal Variable Retarders, see page 56

Custom Liquid Crystal Capabilities

Liquid Crystal Variable Retarders

A basic building block of Meadowlark Optics line of liquid crystal products is the Liquid Crystal Variable Retarder (LCVR). Just one of these devices can replace an entire series of polymer and standard crystalline retarders. They are electronically adjustable from nearly zero waves (or less than with an optional compensator) to over half- wave in the order of 10 milliseconds. With our new Swift LC technology , the switching speeds are symmetric and approximately 150 microseconds. An advanced use of LCVRs is described in the application note "Stokes Polarimetry Using Liquid Crystal Retarders", which is available on our website at www.meadowlark.com.

While we typically list our standard products as the Liquid Crystal Variable Retarder, Attenuator and Polarization Rotator, we also have the ability to utilize Liquid Crystals in other ways that are extremely useful. The Twisted Nematic Liquid Crystal Device (TN) provides our customers with potential for custom applications where a standard LCVR might not be appropriate. At Meadowlark Optics we never cease working on polarization solutions for our customers. We hope the information below will provide our customers with new ideas that will challenge us to create new, exciting solutions for polarization control.

Twisted Nematic Liquid Crystal Cell

One is often only interested in producing two orthogonal linear polarization states of an optical system, or, in the case of a digital optical switch, only two states are frequently required. If you desire to switch the polarization state between only two angles, for example 0° and 90°, a twisted-nematic device is an excellent solution. A big advantage of the twisted nematic device over an LCVR is the simplicity of the driving scheme. High voltage (above ~10 V) gives 0° rotation and low voltage (below ~1 V) gives 90° rotation, so you need not concern yourself with exact voltages or tight tolerances. Also, the field of view is wide when compared to an LCVR because the cell is being used in a situation where the optical axis of the liquid crystal molecules is not at an arbitrary angle to the light but is either parallel or perpendicular to it.

A twisted nematic liquid crystal cell is constructed in the same manner as a standard LCVR except the alignment of the liquid crystal molecules is twisted 90°. As in an LCVR, high voltage (~10 V) aligns the molecules with the field and removes the birefringence and therefore does not affect the light. At low voltage, however, the twist does affect the light, causing rotation of the polarization.

If the twist is gentle when compared to the wavelength of the light, the polarization will simply follow the twist of the liquid crystal molecules. Such a cell is said to be operating in the "Mauguin limit" and its rotation is quite achromatic. The polarization rotation angle is equal to the twist angle for all wavelengths, which are short enough for the twist to be viewed as sufficiently gentle. When this is not the case, the cell will no longer act as a pure rotator. The result of inputting linearly polarized light is no longer an output of rotated linearly polarized light, but rotated elliptically polarized light. However, for certain discrete wavelengths, depending on the birefringence of the liquid crystal and the thickness of the cell, the pure rotation characteristic is retained.

This concept is illustrated in figure 4-2, which shows the transmission (normalized to 1), of a 90° twisted nematic cell between parallel polarizers to be a function of the variable,

$$U = 2d(b/\lambda),$$

where d is the thickness of the cell, b is the birefringence and λ is the wavelength. Where the curve first goes to zero is termed the "first minimum" and this position is typically used. The next highest transmission minimum is called the "second minimum" and so on. In this plot, moving along the horizontal axis can be viewed as increasing thickness or decreasing wavelength.

One might ask, given the achromaticity of thicker cells "why use the first minimum?" The simple answer is speed. The switching speed of an LC is a strong function of the cell thickness; generally, speed drops quadratically with the thickness. Thus, while a cell operating at a particular wavelength in the first minimum condition might switch in 10 to 50 ms, one designed to operate achromatically (for example to transmit <1% between parallel polarizers) over the entire visible range can take several seconds to switch.

NEW from Meadowlark Optics
Swift Liquid Crystal Variable Retarders, see page 56

Custom Liquid Crystal Capabilities

Figure 4-4 shows the high contrasts of several thousands to one, which can be achieved in practice with twisted nematic cells. The curve termed "Normally Black Contrast" was taken between parallel polarizers where low voltage gives a dark state and high voltage yields a bright state. The curve termed "Normally White Contrast" was taken between perpendicular polarizers where the dark state occurs at high voltage.

Custom sizes are available. Please contact your Meadowlark Optics sales engineer for assistance.

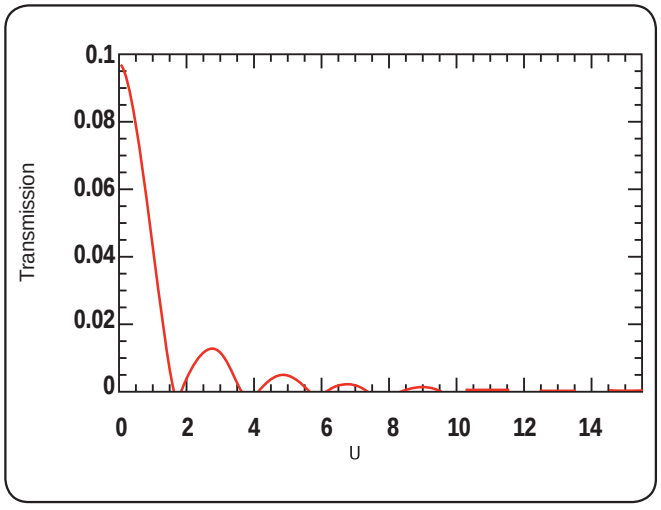


Fig. 4-2 Transmission of a twisted-nematic cell between parallel polarizers as a function of thickness and/or wavelength

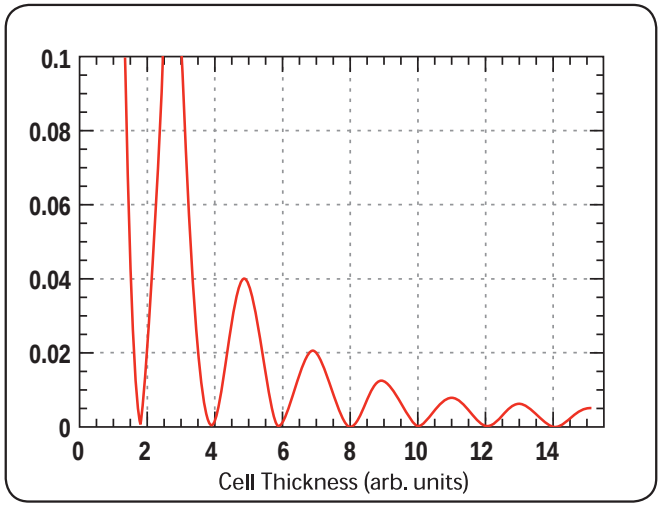


Fig. 4-3 Liquid crystal cell thickness changes

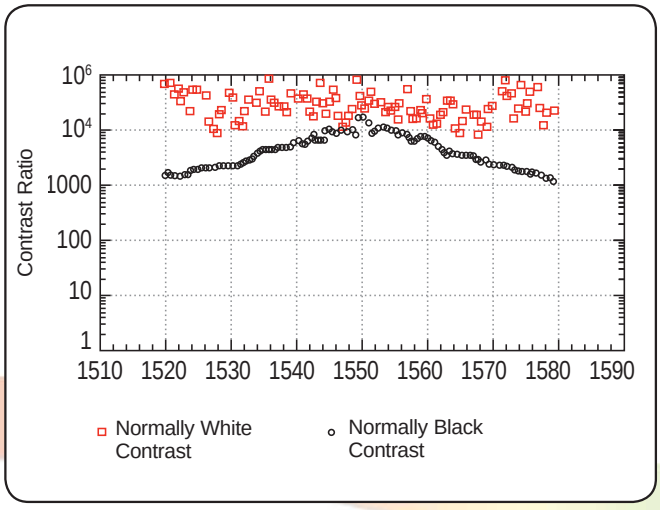


Fig. 4-4 Contrast ratio for a twisted nematic liquid crystal cell

SPECIFICATIONS	
Liquid crystal design space	
Switching Speed	50 µs to several seconds
Wavelength Range	350 nm-2.2 microns
Retardances	(or phase delay) 0 to 10,000 nm.
Extinction Ratio	Up to 50,000:1 for linear polarized monochromatic light
Clear Aperture	1 mm to 100 mm

Liquid Crystal Variable Retarders

These products all use nematic liquid crystal materials to electrically control polarization. Meadowlark Optics standard liquid crystal products provide tunable retardation by changing the effective birefringence of the material with applied voltage, thus altering the input polarized light to any chosen elliptical, linear or circular polarization.

Our precision Liquid Crystal Variable Retarders require unique fabrication and assembly steps. We construct these retarders using optically flat fused silica windows coated with our transparent conductive Indium Tin Oxide (ITO). Our ITO coating is specially designed for maximum transmission from 450 - 1800 nm (see Figure 4.5).

A thin dielectric layer is applied over the ITO and gently rubbed, to provide for liquid crystal molecular alignment. Two windows are then carefully aligned and spaced a few microns apart. The cavity is filled with birefringent nematic liquid crystal material. Electrical contacts are attached and the device is environmentally sealed. We carefully place the Liquid Crystal Variable Retarder in an anodized aluminum housing such that the fast and slow axes are both at 45° relative to a convenient mounting hole.

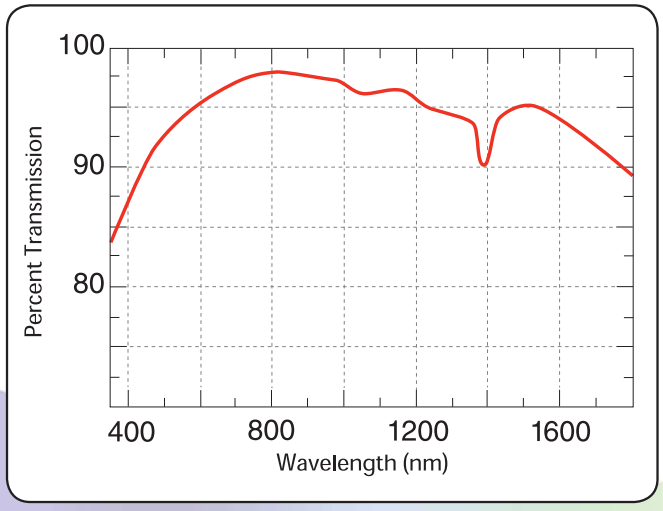


Fig. 4-5 Typical transmission through an uncoated liquid crystal device

Anisotropic nematic liquid crystal molecules form uniaxial birefringent layers in the liquid crystal cell. An essential feature of nematic material is that, on average, molecules are aligned with their long axes parallel, but with their centers randomly distributed as shown in figure 4-6(a). With no voltage applied, the liquid crystal molecules lie parallel to the glass substrates and maximum retardation is achieved.

When voltage is applied, liquid crystal molecules begin to tip perpendicular to the fused silica windows as shown in figure 4-6(b). As voltage increases, molecules tip further causing a reduction in the effective birefringence and hence, retardance. Molecules at the surface, however, are unable to rotate freely because they are pinned at the alignment layer. This surface pinning causes a residual retardance of ~30 nm even at high voltage (20 volts).

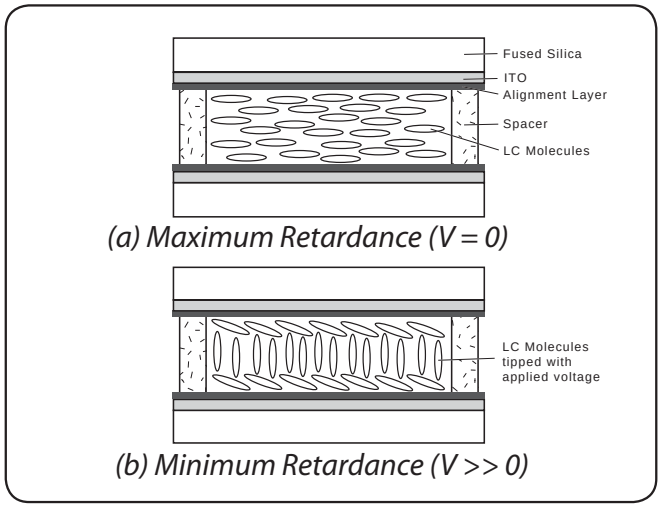


Fig. 4-6 Liquid Crystal Variable Retarder construction showing molecular alignment (a) without and (b) with applied voltage

We achieve zero (or any custom) retardance with a subtractive fixed polymer retarder, called a compensator, attached to the liquid crystal cell. Negative retardance values are sometimes preferred, for example, when converting between right- and left-circularly polarized states. Figure 4-8 illustrates retardance as a function of voltage for a typical Liquid Crystal Variable Retarder with and without an attached compensator. Placing a compensated Liquid Crystal Variable Retarder between two high extinction polarizers creates an excellent optical attenuator, with convenient electronic control.

As with any anisotropic material, retardance is dependent upon thickness and birefringence. Liquid crystal material birefringence depends on operating wavelength, drive voltage and temperature. The overall retardance of a liquid crystal cell decreases with increasing temperature (approximately -0.4% per °C).

Liquid Crystal Variable Retarders

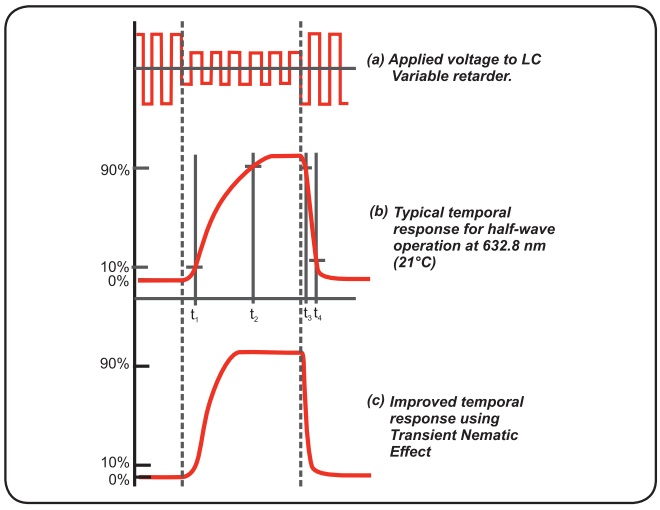


Fig.4-7 Temporal response of LC Variable Retarder
The applied voltage is a 2 kHz square wave.
Excessive DC voltage will damage the liquid crystal

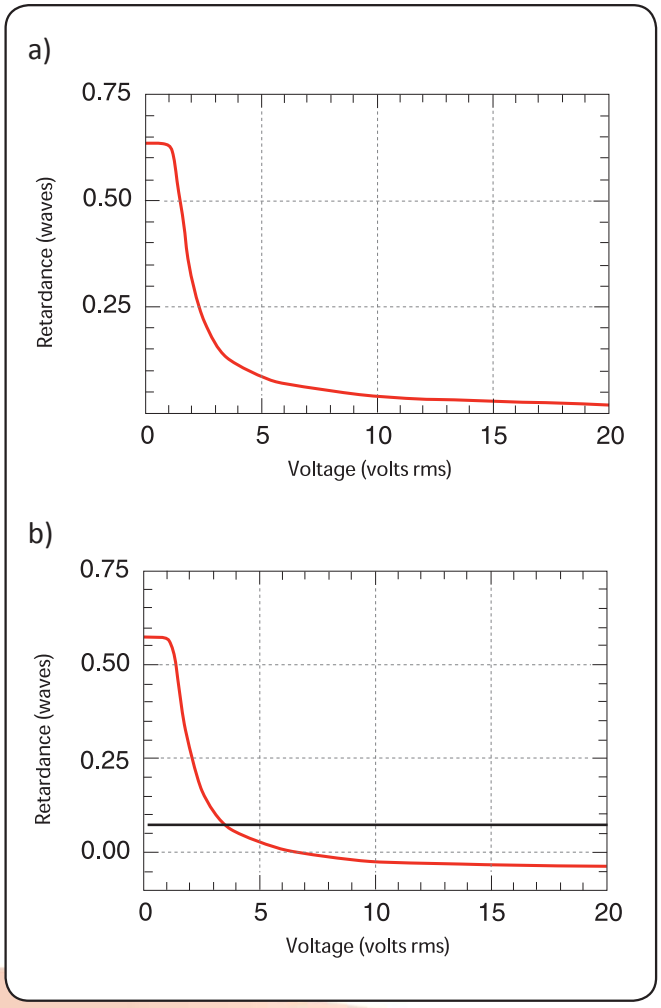


Fig.4-8 Liquid Crystal Variable Retarder performance versus applied voltage at 632.8 nm, 21° C.
(a) without compensator and
(b) with compensator

Response Time

Liquid Crystal Variable Retarder response time depends on several parameters, including layer thickness, viscosity, temperature, variations in drive voltage and surface treatment. Liquid crystal response time is proportional to the square of the layer thickness and therefore, the square of the total retardance.

Response time also depends upon direction of the retardance change. If the retardance increases, response time is determined solely by mechanical relaxation of the molecules. If retardance decreases in value, response time is much faster due to the increased electric field across the liquid crystal layer. Typical response time for our standard visible Liquid Crystal Variable Retarder is shown in figure 4-7b. It takes about 5 ms to switch from one-half to zero waves (low to high voltage) and about 20 ms to switch from zero to one-half wave (high to low voltage).

Response time improves by using custom materials with high birefringence and a thinner liquid crystal layer. At higher temperature, material viscosity decreases, also contributing to a faster response. For speed critical applications, see page 56 for Swift LC devices.

Another technique involves the Transient Nematic Effect (TNE) to improve response times. With this drive method, a high voltage spike is applied to accelerate the molecular alignment parallel to the applied field. Voltage is then reduced to achieve the desired retardance. When switching from low to high retardance all voltage is momentarily removed to allow the liquid crystal molecules to undergo natural relaxation. Response time achieved with the transient nematic effect is also shown in figure 4-7c. Our Four Channel Digital Interface described on pages 60-61 conveniently provides the necessary TNE voltage profiles.

Our standard Liquid Crystal Variable Retarders provide a minimum retardance range of ~30 nm to at least half-wave at the specified wavelength. With an attached compensator, retardance is guaranteed to range from zero to at least half-wave at the specified wavelength. Custom retardance ranges (up to a few waves) and custom compensators are available. Contact our Sales Department to discuss your requirements.

Each Liquid Crystal Variable Retarder is supplied with retardance versus voltage performance data for your specified wavelength. A coaxial cable with mating connector is provided for easy attachment to one of our electronic controllers.

QUESTION

"The temporal response of a liquid-crystal device seems very complicated. Where can I find some clarification?"

ANSWER

See our Application Note on temporal response of liquid crystal devices at www.meadowlark.com.

Liquid Crystal Variable Retarders

Liquid crystal devices should be electrically driven with an AC waveform with no DC component to prevent ionic buildup which can damage the liquid crystal layer. We require a 2 kHz square wave of adjustable amplitude for controlling our Liquid Crystal Variable Retarders (LCVR). Our Basic Controller and Four Channel Interface described on pages 59-61 ensure these drive requirements are met. A temperature sensing and control option can be added to our LCVRs for accurate controlling of the operating temperature. The sensor is attached directly to the LCVR substrate, outside its clear aperture. Without this option, retardance decreases by approximately 0.2% to 0.3% per °C increase in temperature.

Key Benefits

- **Computer control capability**
- **Temperature control options**
- **Usable from 450 to 1800 nm**
- **Precision non-mechanical retardation control**

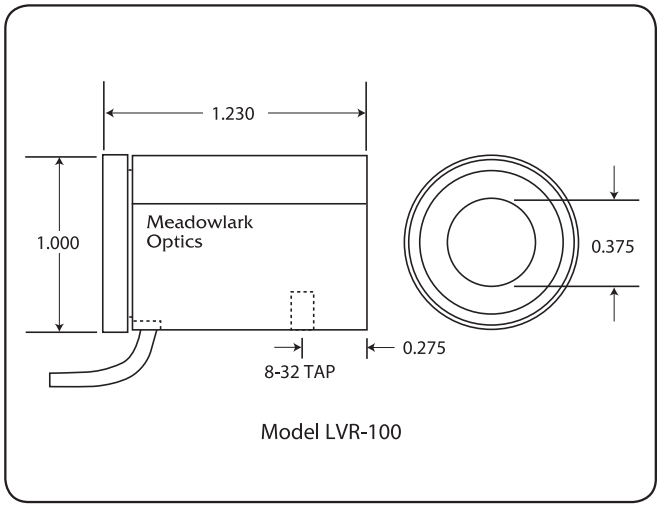


Fig. 4-9 Model LVR-100 dimensions
All dimensions in inches

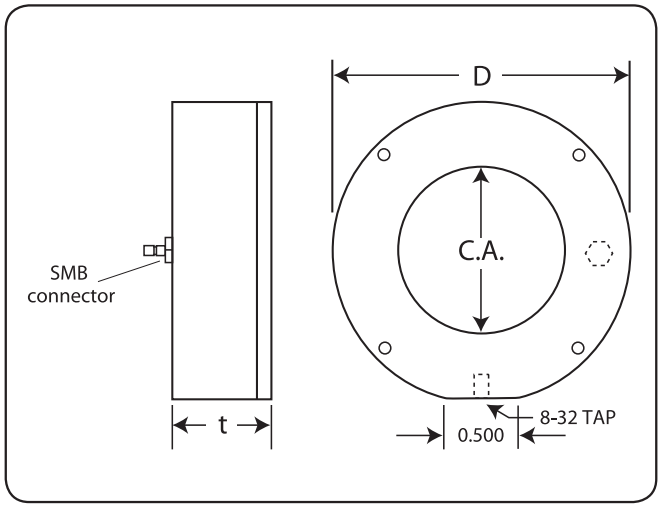


Fig. 4-10 Models LVR-200 and LVR-300 dimensions
All dimensions in inches

SPECIFICATIONS	
Retarder Material	Nematic liquid crystal
Substrate Material	Optical quality synthetic fused silica
Wavelength Range	450-1800 nm (specify)
Retardance Range	
Without compensator With compensator	~30 nm to λ/2 0 to λ/2 custom ranges are available
Transmitted Wavefront Distortion (at 632.8 nm)	≤ λ/4
Surface Quality	40-20 scratch and dig
Beam Deviation	≤ 2 arc min
Reflectance (per surface)	≤ 0.5% at normal incidence
Diameter Tolerance	± 0.005 in.
Temperature Range	0° C to 50°C
Recommended Safe Operating Limit	500 W/cm², CW 300 mJ/cm², 10 ns, visible

ORDERING INFORMATION

Diameter, D (in.)	*Clear Aperture, CA (in.)*	*Thickness t (in.)*	*Part Number*
Without Attached Compensator (30 nm to λ/2)			
1.00	0.37	1.23	LVR - 100
2.00	0.70	0.75	LVR - 200
3.00	1.60	1.00	LVR - 300
With Attached Compensator (0 nm to λ/2)			
1.00	0.37	1.23	LRC - 100
2.00	0.70	0.75	LRC - 200
3.00	1.60	1.00	LRC - 300

We offer standard liquid crystal variable retarders to cover four spectral regions:

VIS: 450 - 700 nm IR 1: 650 - 950 nm
IR 2: 900 - 1250 nm IR 3: 1200 - 1700 nm

Please specify spectral region when placing your order.
For temperature control option, append-TSC to part number .

Liquid Crystal Variable Attenuators

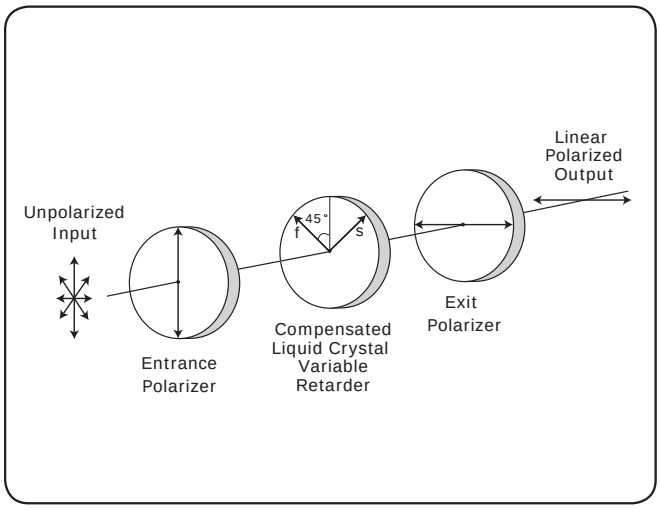


Fig. 4-11 Standard Liquid Crystal Variable Attenuator design uses crossed linear polarizers

Key Benefits

- **High contrast ratio**
- **Computer control capability**
- **Continuous control of light intensity**

Meadowlark Optics Liquid Crystal (LC) Variable Attenuator offers real-time, continuous control of light intensity. Our attenuator consists of an LC Variable Retarder (with attached compensator) operating between crossed linear polarizers.

With crossed polarizers, light transmission is maximized by applying the correct voltage to achieve half-wave retardance from the LC cell as shown in figure 4-11. Half-wave operation rotates the incoming polarization direction by 90°, so that light is passed by the second polarizer. Minimum transmission is obtained with the retarder operating at zero (or a whole number of) waves.

Transmission decreases as the applied AC voltage amplitude increases (half- to zero-waves retardance). The relationship between transmittance T and retardance θ (in degrees) for crossed polarizer configuration is given by:

$$T(\theta) = 1/2\ [1 - \cos(\theta)]\ T_{max}$$

where T_{max} is the maximum transmittance when retardance is exactly one-half wave (or 180°). Figure 4-12 shows transmittance as a function of applied voltage.

Maximum transmission is dependent upon properties of the LC Variable Retarder as well as the polarizers used in your system. Figure 4-13 shows the transmission of an LC Variable Attenuator optimized for use at 550 nm with crossed polarizers. An unpolarized light source is used for illumination.

Contrast ratio is defined as the maximum transmission (obtained with the LC cell at half-wave operation) divided by the minimum transmission (obtained with the LC cell at zero waves). Values exceeding 1000:1 (see figure 4-14) can be obtained for a single wavelength by optimizing the applied voltage levels for minimum and maximum transmission. We guarantee a minimum contrast ratio of 500:1 at your specified wavelength.

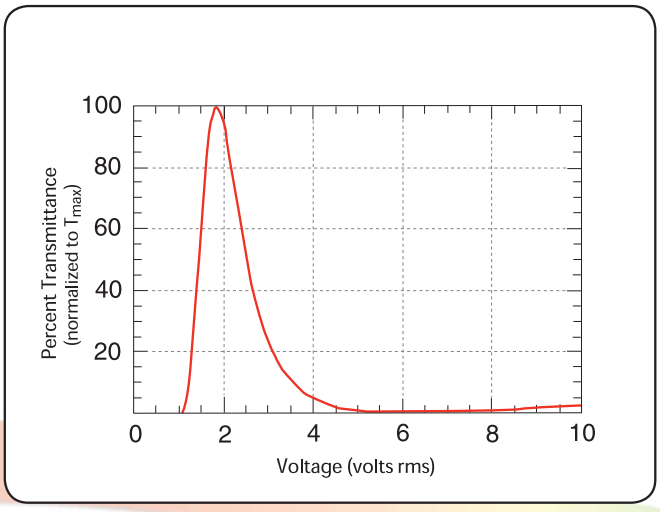


Fig. 4-12 Normalized transmittance of Liquid Crystal Variable Attenuator with crossed linear polarizers at a single wavelength

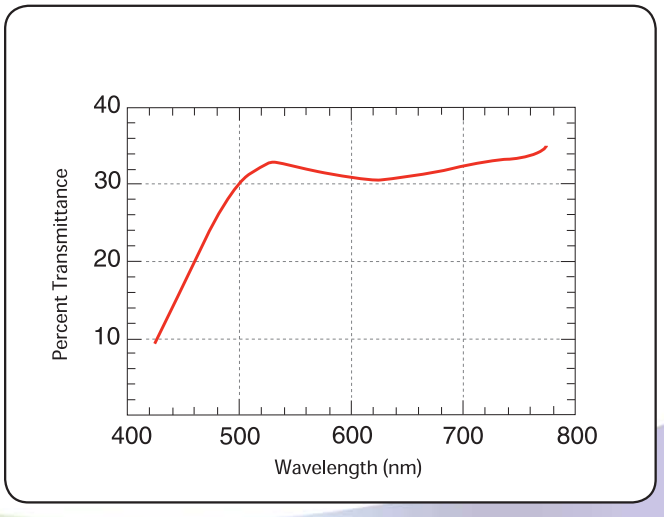


Fig. 4-13 Unpolarized Transmittance as a function of wavelength for LC Variable Attenuator, optimized for 550 nm, with polarizers and unpolarized input

Liquid Crystal Variable Attenuators

A Liquid Crystal Variable Attenuator can be configured with high efficiency calcite or beamsplitting polarizers to maximize light transmittance and increase damage threshold. With a linearly polarized input beam and a calcite polarizer, transmittance values exceed 90% at most wavelengths. Very high contrast ratios, in excess of 5000:1, can be achieved with custom double attenuators. In this design, two Liquid Crystal Variable Retarders are combined with three polarizers.

Custom devices for near infrared applications, utilizing appropriate dichroic polarizers, can also be manufactured. Please see the section on Polarizers for a selection of available polarizers.

Our Basic Controller and Four Channel Interface described on pages 59-61 offer the precision waveforms necessary to obtain accurate and repeatable intensity control for your application.

SPECIFICATIONS	
Retarder Material	Nematic liquid crystal with Birefringent polymer
Polarizer Material	Dichroic polymer
Substrate Material	Optical quality synthetic fused silica
Wavelength Range **Visible** **Near Infared 1** **Near Infared 2**	 450-700 nm 700-900 nm 900-1550 nm
Contrast Ratio	500:1 at single wavelength
Transmitted Wavefront Distortion (at 632.8 nm)	≤ λ/4 (each component)
Surface Quality	40-20 scratch and dig
Beam Deviation	≤ 2 arc min
Reflectance (per surface)	≤ 0.5% at normal incidence
Diameter Tolerance	±0.005 in.
Temperature Range	0° C to +50° C
Recommended Safe Operating Limit	1 W/cm², CW (with dichroic polarizers)

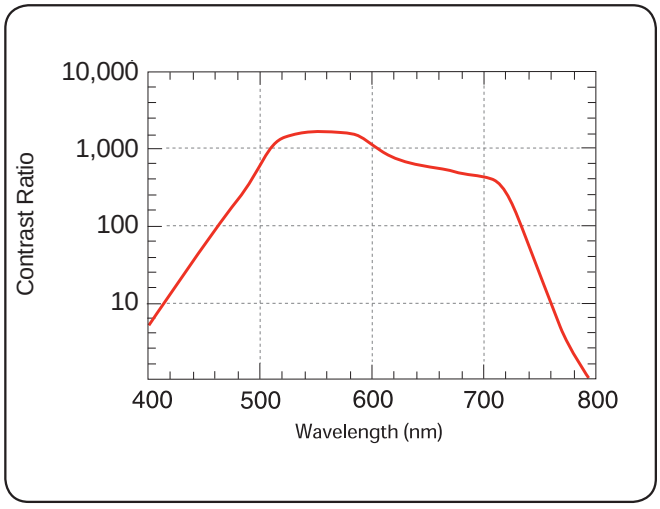


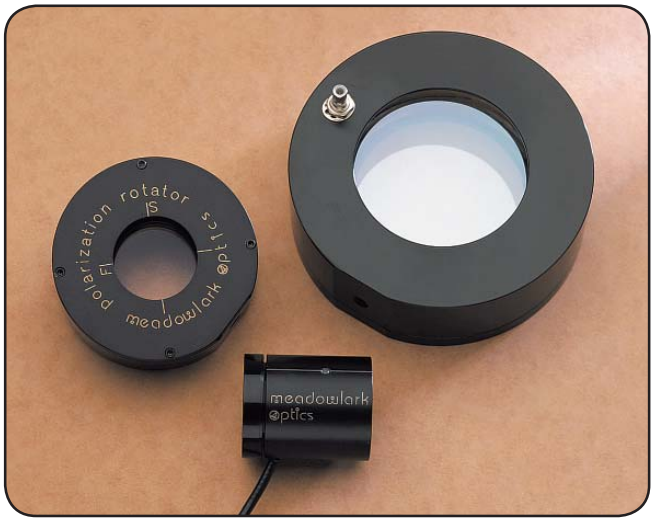
Fig. 4-14 Typical Contrast Ratio of a Liquid Crystal Variable Attenuator optimized at 550 nm

ORDERING INFORMATION			
Diameter, D (in.)	*Clear Aperture,CA (in.)*	*Thickness t (in.)*	*Part Number*
1.00	0.37	1.23	LVA - 100-λ
2.00	0.70	0.75	LVA - 200-λ
3.00	1.60	1.00	LVA - 300-λ

Please specify operating wavelength λ in nanometers when placing your order.

Custom sizes are available.

Liquid Crystal Polarization Rotators



Key Benefits

- High power capability
- High polarization purity
- Computer control capability
- 180 degree polarization rotation
- Continuous rotation of linearly polarized light

Our Liquid Crystal Polarization Rotator continuously rotates the polarization direction of a monochromatic, linearly polarized input beam. Our design consists of a Liquid Crystal Variable Retarder combined with a zero-order polymer quarter-wave retarder. The fast axis of the liquid crystal variable retarder is oriented at 45° to the slow axis of the quarter-wave retarder. Linearly polarized input must be parallel to the quarter-wave retarder slow axis. Polarization rotation is achieved by electrically controlling the retardance of the Liquid Crystal Variable Retarder, eliminating any mechanical motion.

A quarter-wave retarder converts elliptical polarization formed by the Liquid Crystal Variable Retarder to linear polarization. The rotation angle is equal to one-half the retardance change from the Liquid Crystal Variable Retarder.

Response time depends upon the desired amount of rotation. Small rotations have longer response times.

Polarization purity is defined as the ratio of the rotated linear component to the orthogonal component. A selected rotation is very sensitive to applied voltage and operating temperature. On average, polarization purity (or contrast ratio) is better than 150:1.

We provide test data including the required voltages corresponding to polarization orientations from approximately -40° to approximately 140° rotation in 10° increments. These measurements are taken at room temperature for your specified wavelength.

Standard Liquid Crystal Polarization Rotators are supplied without an input polarizer. Input polarization direction must be precisely aligned for optimum performance. Please call if you require an input polarizer.

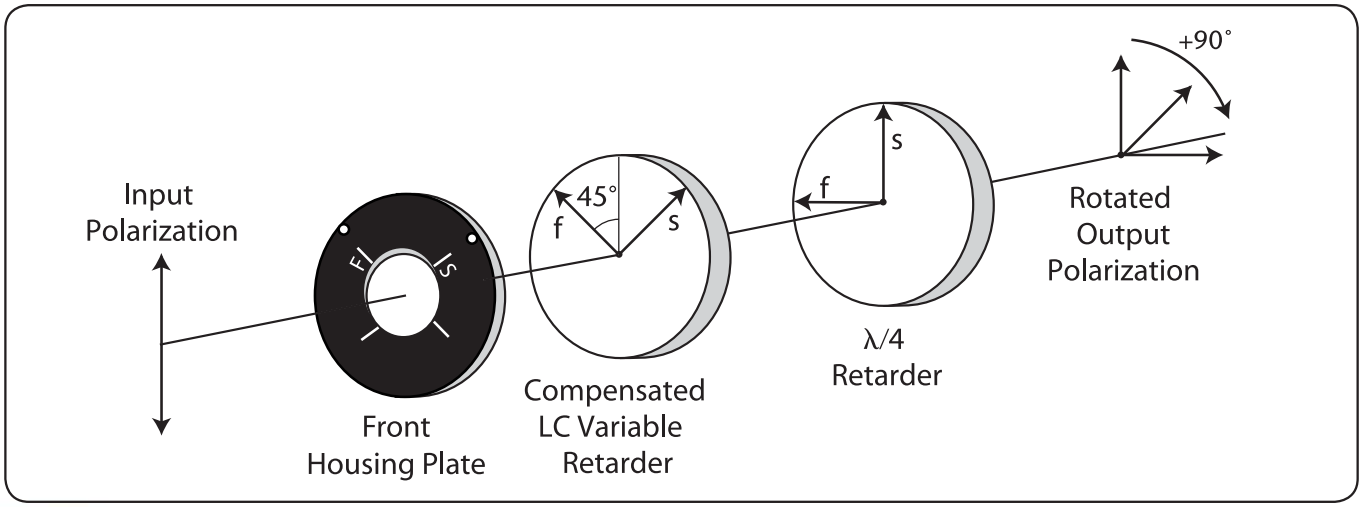


Fig. 4-15 Operation of Liquid Crystal Polarization Rotator showing complete rotation of a linearly polarized input beam

Liquid Crystal Polarization Rotators

SPECIFICATIONS	
Retarder Material	Nematic liquid crystal with Birefringent polymer
Substrate Material	Optical quality synthetic fused silica
Wavelength	450-1800 nm (specify)
Polarization Rotation	180° or more
Polarization Purity	150:1 average
Transmittance	> 92% with polarized input
Transmitted Wavefront Distortion (at 632.8 nm)	≤ λ/4
Surface Quality	40-20 scratch and dig
Beam Deviation	≤ 2 arc min
Reflectance (per surface)	≤ 0.5% at normal incidence
Diameter Tolerance	±0.005 in.
Temperature Range	0° C to 50° C
Recommended Safe Operating Limit	500 W/cm², CW 300 mJ/cm², 10 ns, visible

ORDERING INFORMATION

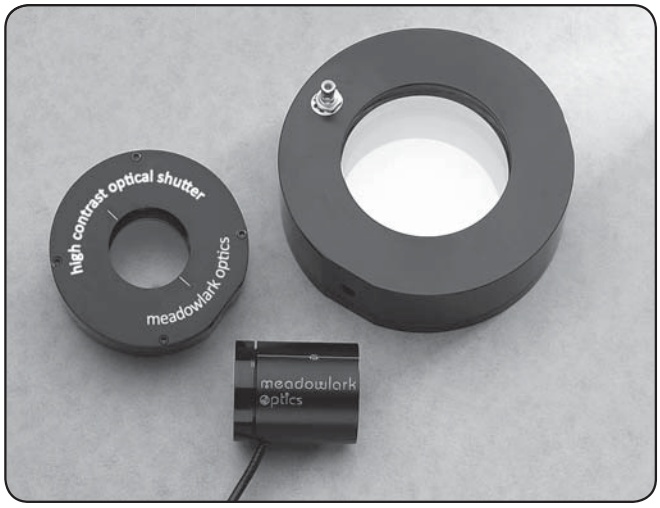
Diameter, D (in.)	*Clear Aperture, CA (in.)*	*Thickness t (in.)*	*Part Number*
1.00	0.37	1.23	LPR - 100-λ
2.00	0.70	0.75	LPR - 200-λ
3.00	1.60	1.00	LPR - 300-λ

Please specify operating wavelength λ in nanometers when placing your order.

Custom sizes are available. Please contact our Sales Department for a custom quote.

NEW

High Contrast Optical Shutter



Key Benefits

- **High Contrast**
- **No mechanical motion**
- **Computer control capability**
- **No vibration**

This liquid crystal shutter is a vibration-free alternative to mechanical shutter that is especially convenient for use in polarized light beams. The liquid crystal switches between a state that rotates the input polarization by 90° with no voltage applied and a state that makes no change in the input polarization with 8 to 10 volts applied. The applied voltage is 2 kHz AC as supplied by our 4010, 3040 or 3050 liquid crystal drivers. The liquid crystal configuration is twisted nematic. The shutter is supplied with integral dichroic visible polarizers that function over the wavelength range of 450 nm to 700 to provide an average contrast ratio of better than 1,000:1 over this wavelength range. Shutters with larger aperture sizes and with wavelength coverage to 2.1 microns are available on a custom basis. Please call with your special requirements.

SPECIFICATIONS	
Liquid crystal configuration	Twisted nematic
Substrate Material	Optical quality synthetic fused silica
Polarizer Material	Dichroic Polymer
Wavelength Range	450-700 nm
Contrast Ratio (average)	1,000:1
Angular Field of View	25° incidence angle with some reduction above 10°
Switching Time (10% to 90%) at room temperature	
Closed to open: Open to closed	5 milliseconds 0.4 milliseconds
Transmitted Wavefront Distortion (at 632.8 nm)	≤ λ/2
Surface Quality	60-40 scratch and dig
Reflectance (per surface)	≤ 0.5% at normal incidence
Beam Deviation	≤ 5 arc min
Recommended Safe Operating Limit	1 W/cm², CW
Glass Thickness	0.48 — 0.52 inches
Polarization Direction	Vertical on input face, horizontal on output face
Storage temperature	-20° C to +80° C
Operating temperature	0° C to +50° C

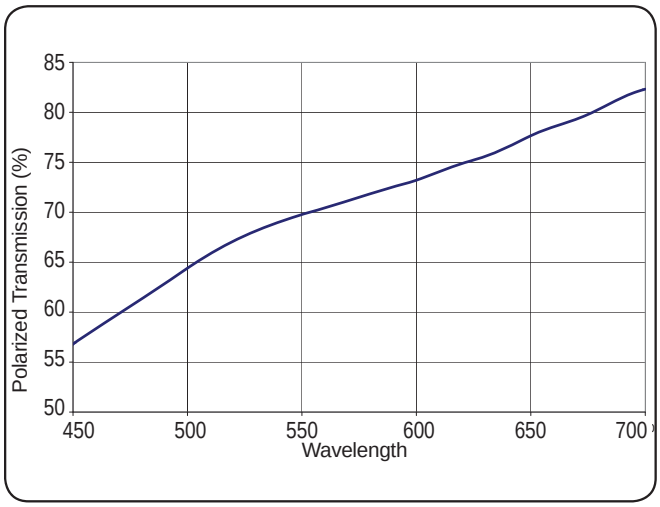


Fig. 4-16 Transmission for Polarized Light

ORDERING INFORMATION			
Diameter, D (in.)	*Clear Aperture, CA (in.)*	*Thickness t (in.)*	*Part Number*
1.00	0.37	1.23	LCS - 100
2.00	0.70	0.75	LCS - 200
3.00	1.60	1.00	LCS - 300

Swift Liquid Crystal Principles

Meadowlark Optics next generation liquid crystal variable devices utilizes a new bulk stabilized polymer liquid crystal formulation. With switching speeds of less than a 150 microseconds in both directions our new "Swift" Liquid Crystal devices are perfect for applications where response time is critical.

Swift Liquid Crystal Technology

Liquid crystal polymer composite materials have been studied extensively is the past decades because of their intriguing physics and their potential application in robust, fast-switching liquid crystal devices. Meadowlark Optics has developed a novel fabrication process in which a polymer network is utilized to enhance the electro-optical performance of our liquid crystal devices.

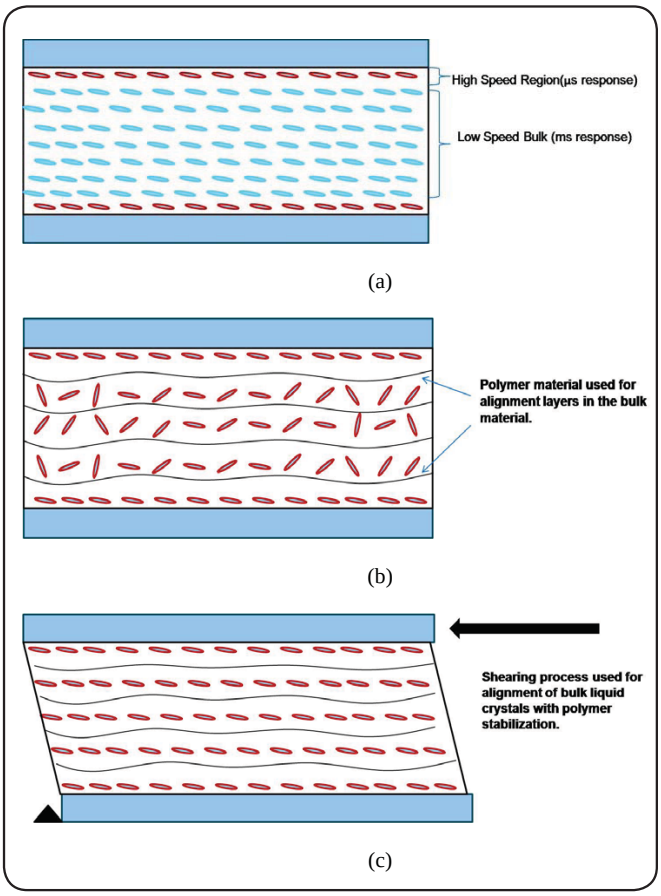

High Speed Region(µs response)
Low Speed Bulk (ms response)
(a)
Polymer material used for alignment layers in the bulk material.
(b)
Shearing process used for alignment of bulk liquid crystals with polymer stabilization.
(c)

Fig. 4-17 (a) Typical bulk liquid crystal device showing both regions of fast and slow electro-optical response.

(b) A polymer stabilized liquid crystal device showing random alignment in the bulk of the material.

(c) A Swift Liquid Crystal device after alignment process.

Typical bulk liquid crystal devices, such as Meadowlarks' LCVR, have response times that are governed by the bulk of the liquid crystal and are a function of cell gap.

As cell gap increases, switching times increase as the square of the thickness. This effect is due to molecular properties of the bulk liquid crystal material and the alignment layer of the cell (See Figure 4-6). The actual temporal electro-optical response of the cell has two components, (1) a very fast surface layer effect that occurs very close to the alignment layer and is on the order of microseconds and (2) a relatively slow response that occurs in the bulk of the material on the order of milliseconds. This second response dominates in a typical bulk liquid crystal device. Figure 4-17 (a) defines these two regions for a standard liquid crystal variable retarder cell. To overcome this effect the introduction of small amounts of polymer material into the bulk allow for a multitude of alignment surfaces for the liquid crystal material. This allows for alignment surface effects throughout the bulk of the cell (Figure 4-17 (b)). The addition of a polymer stabilizing material in the bulk essentially decouples the cell gap from the switching speed. The challenge to this type of device is now there are no means for uniform liquid crystal alignment in the bulk, such that after infiltration of polymer material; the liquid crystal is aligned in random fashion with no particular "fast-axis" for functional retarder devices. For liquid crystal alignment to occur Meadowlark Optics performs a mechanical shearing process on the devices that aligns the bulk liquid crystal material (Figure 4-17 (c)). Once this step is performed the cell is locked into place and sealed. This assembly process ensures excellent uniformity in alignment of the liquid crystal molecules and gives a retardance uniformity across the clear aperture of less than 20nm.

Meadowlark Optics Swift liquid crystal technologies can be used throughout the visible and near infrared region. While these devices, like all liquid crystal devices, are affected by temperature and wavelength changes, they can be calibrated to accommodate those differences. Each Swift liquid crystal variable retarder is supplied with retardance versus voltage performance data for your specified wavelength, while our shutter devices are provided with temporal performance data. A coaxial cable with mating connector is provided for easy attachment to one of our new high voltage power supply sources.

NEW

Swift Liquid Crystal Variable Retarders

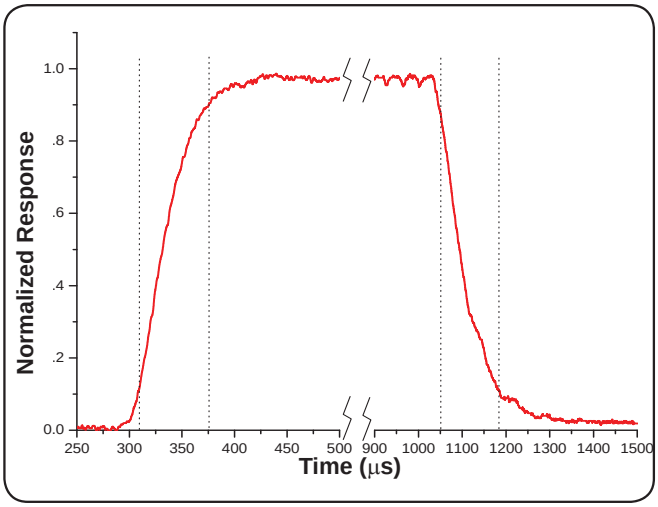


Fig. 4-18 Swift Liquid Crystal Response Time Plot

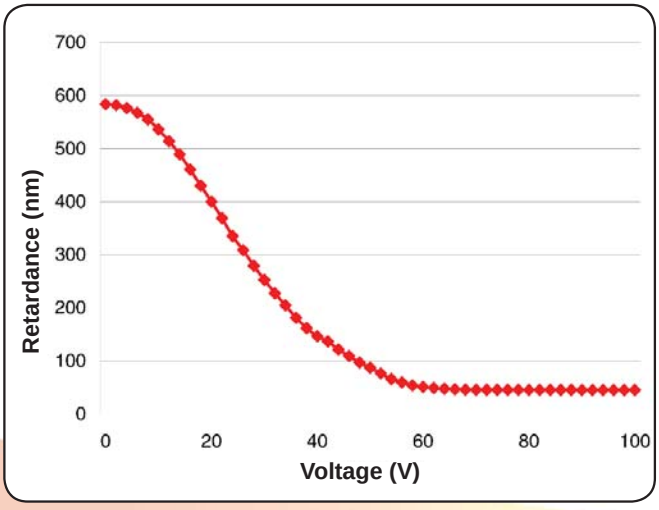


Fig. 4-19 Swift Liquid Crystal Retardance vs Voltage

Key Benefits

- **Sub-millisecond response times**
- **Computer control capability**
- **Temperature control options**
- **Performance from 450 to 1800 nm**

The next generation of liquid crystal variable retarders utilizes a new bulk stabilized polymer liquid crystal formulation. With switching speeds of less than a 150 microseconds in both directions the Swift Liquid Crystal Variable Retarder (SLCVR) is perfect for applications where response time is critical. The SLCVRs require a high voltage (< 100 Vrms) 13 kHz square wave of adjustable amplitude that is provided by our D3060HV High Voltage Interface (see page 62). A temperature sensing and control option can be added to our SLCVRs for accurate controlling of the operating temperature. The thermal sensor is attached directly to the SLCVR substrate, outside the clear aperture. Custom SLCVRs are available for a variety of applications.

SPECIFICATIONS	
Retarder Material	Polymer stabilized nematic liquid crystals
Substrate Material	Optical quality synthetic fused silica
Response Time (10-90%)	≤ 175 μs (zero to half-wave) ≤ 175 μs (half-wave to zero)
Contrast Ratio	150:1, minimum
Retardance Range	
Without compensator With compensator	~50 nm to λ/2 0 to λ/2 custom ranges are available
Transmitted Wavefront Distortion (at 632.8 nm)	≤ λ/2
Surface Quality	40-20 scratch and dig
Beam Deviation:	≤ 2 arc min
Reflectance (per surface):	≤ 0.5% at normal incidence
Diameter Tolerance	± 0.005 in.
Storage Temperature	-20° C to 80° C
Operating Temperature	0° C to 55° C
Wavelength Range	VIS: 450-700 nm IR 1: 650-950 nm IR 2: 900-1250 nm IR 3: 1200-1700 nm

ORDERING INFORMATION

Diameter, D (in.)	*Clear Aperture, CA (in.)*	*Thickness t (in.)*	*Part Number*
Without Attached Compensator (50 nm to λ/2)			
2.00	0.70	0.75	SVR - 200
With Attached Compensator (0 nm to λ/2)			
2.00	0.70	0.75	SRC - 200

Please specify spectral region when placing your order.

NEW

Swift Optical Shutters

Key Benefits

- No mechanical motion
- Computer control capability
- Noiseless
- High speed

This liquid crystal shutter is a vibration-free alternative to mechanical shutters for use in high- speed shutter applications. It uses a Swift LC cell between crossed polarizers to provide sub-millisecond switching for both opening and closing. Switching time is 125 microseconds to open and 125 microseconds to close. The switching times are less than 50 microseconds if the shutter is heated to 40° C. The D3060HV controller provides this temperature control capability. These shutters show some haziness in the liquid crystal layer in the blue and green wavelengths. The light loss from this haze is about 1% at 700 nm but increases monotonically to about 10% loss at 450 nm. Scatter at wavelengths above 700 nm is negligible. The shutter is supplied with integral dichroic visible polarizers that function over the wavelength range of 450 nm to 700 nm to provide an average contrast ratio of better than 200:1. Shutters with larger aperture sizes and with wavelength coverage to 2.1 microns are available on a custom basis. Please call with your special requirements.

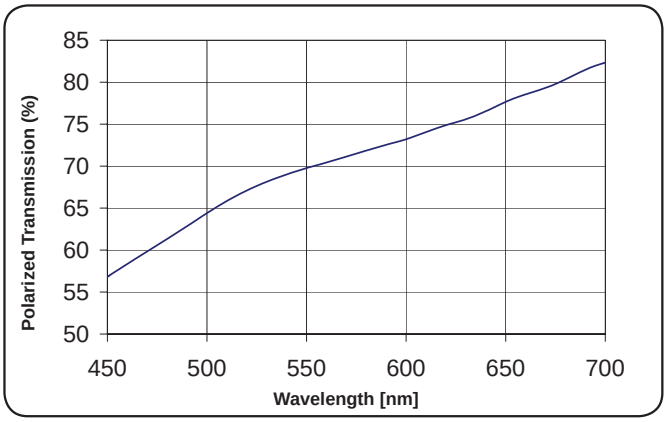


Fig. 4-20 Polarized transmission of the Swift Optical Shutter in the open state

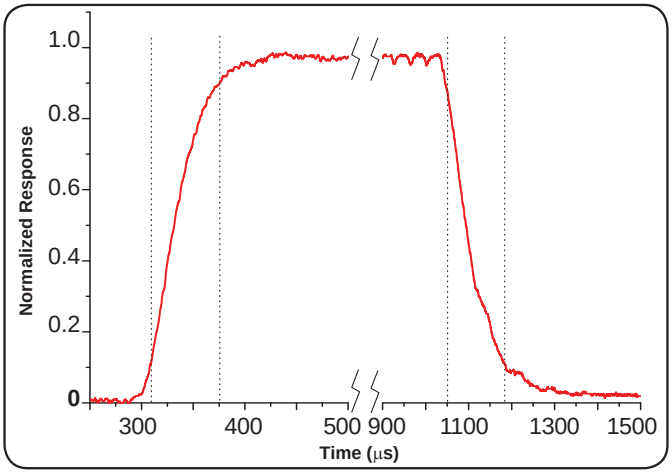


Fig. 4-21 Swift LC Response Time Plot

ORDERING INFORMATION			
Diameter, D (in.)	*Clear Aperture, CA (in.)*	*Thickness t (in.)*	*Part Number*
2.00	0.70	0.75	SCS - 200

SPECIFICATIONS	
Retarder Material	Polymer stabilized nematic liquid crystals
Substrate Material	Optical quality synthetic fused silica
Polarizer Material	Dichroic Polymer
Wavelength Range	450-700 nm
Contrast Ratio (average)	200:1
Angular Field of View	± 5 ° incidence angle
Switching Time (10% to 90%) at room temperature	
Closed to open: Open to closed	150 µs 150 µs
Switching Time (10% to 90%) at 40° C	50 µs
Transmitted Wavefront Distortion (at 632.8 nm)	≤ λ/2
Surface Quality	60-40 scratch and dig
Reflectance (per surface):	≤ 0.5% at normal incidence
Beam Deviation	≤ 5 arc min
Recommended Safe Operating Limit	1 W/cm², CW 300 mJ/cm², 10 ns, visible
Glass Thickness	0.48 — 0.52 inches
Polarization Direction	Vertical on input face, horizontal on output face
Storage temperature	-20° C to +70° C
Operating temperature	-10° C to +60° C

NEW

Basic Liquid Crystal Controller

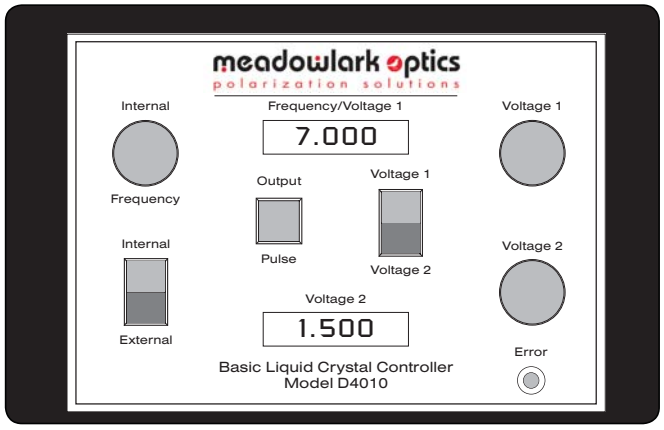


Fig. 5-1 Model D4010 Basic Liquid Controller front panel layout

Meadowlark Optics is excited to announce the release of the Model D4010, our new Basic Liquid Crystal Controller. This liquid crystal (LC) driver is designed to integrate with any single (standard) Meadowlark Optics LC device currently offered as well as any nematic Liquid Crystal device compatible with the specifications listed. Digital LED voltage and frequency readouts provide added convenience. Now, frequency and voltage settings can be easily stored by simply pressing the adjustment knob. Also, system memory retains voltage and frequency settings at power down.

With a Liquid Crystal Variable Retarder, manual adjustment of the voltage amplitude controls the device retardance. Figure 4-8 on page 49 illustrates the relationship between voltage and retardance.

Independent voltage settings allow easy and repeatable selection of two retardance values. Often, it is desirable to modulate between the two states. For example, switching between quarter-wave and half-wave retardance changes linearly polarized light to either left or right circular. A manual toggle allows easy switching between two states.

Key Benefits:

- **Convenient, stand-alone bench top operation**
- **Versatile - compatible with all standard Meadowlark Optics LC devices and other nematic liquid crystal devices with compatible listed specifications**
- **System memory retains voltage and frequency settings at power down**
- **Bright green, digital LED voltage and frequency readouts**
- **SMA and BNC outputs, with no adapters required**
- **Voltage and frequency save and restore function**
- **Out-of-the-box functionality. Sets up in minutes.**
- **Safe, low voltage operation. Fuse protected.**
- **Intuitive operation. Compact. Easy to use.**
- **ROHS and CE compliant**
- **Low DC bias protects liquid crystal**

Model D4010 comes equipped with its own internal modulation control. The Internal Frequency knob adjusts periodic switching between the two voltage settings. An external input allows modulation to run synchronously with other equipment.

Each Meadowlark Optics Liquid Crystal Variable Retarder is supplied with a plot of its actual retardance versus voltage. Using your Model D4010 Controller and this retardance plot ensures accurate retardance to voltage correlation.

SPECIFICATIONS	
Output Voltage	0 to 20 V rms, maximum
Voltage Resolution	± 1 mV for < 10 V output ± 10 mV for ≥ 10 V output
Fundamental Drive Waveform	2 kHz ac square wave
External Modulation (input)	TTL compatible 5 V maximum
Output Bias	± 5 mV dc, maximum
Power Requirements	100 – 240 V ac 47 – 63 Hz 500 mA
Internal Frequency (modulation)	0.5 – 150 Hz 50% duty cycle
External Frequency (modulation)	DC – 500 Hz, variable duty cycle allowable
External Dimensions (W x D x H)	7.0 x 5.0 x 3.0 in.
CE Compliance	Compliant

ORDERING INFORMATION	
Basic LC Controller	D4010

Two year and three year extended warranty options available, please contact your Meadowlark Optics sales engineer

Four Channel Digital Interface

Key Benefits:

- **USB or RS232 interface**
- **C++ code examples including .dll libraries**
- **Compact and simple to use**
- **Microsoft® HyperTerminal configuration file included**
- **Independent control of voltage levels on four channels to 1 mV resolution**
- **Includes National Instruments LabVIEW™ Virtual Instrument drivers to interface with custom software**

The Four Channel Digital Interface is designed for high precision computer control of up to four Meadowlark Optics nematic liquid crystal devices at one time and is available in either Basic or Advanced Package options.

The D3040 Basic comes with CellDRIVE 3000 Basic software to allow independent control of the amplitude of the 2 kHz square wave drive for four separate nematic liquid crystal cells.

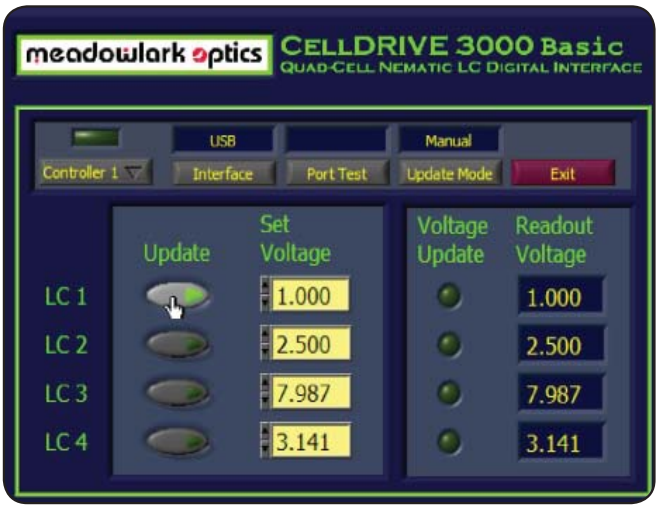


Fig. 5-2 Basic D3040 operation enables computer control for up to four Liquid Crystal Variable Retarders

The D3050 Advanced Package includes all the functionality of the Basic Package plus the added features of the CellDRIVE 3100 Advanced software and capability for temperature monitoring and control on one channel. The Advanced Package allows the amplitude of the 2 kHz square wave output to be driven either by an external DC analog signal supplied to a front panel connector or specific CellDRIVE generated waveforms including sinusoidal, square, triangle, sawtooth and transient nematic effect waveforms. Additional functions include the capability to output a sync pulse on a front panel connector at desired points in the CellDRIVE generated waveforms and the ability to save/restore all CellDRIVE settings to/from a file.

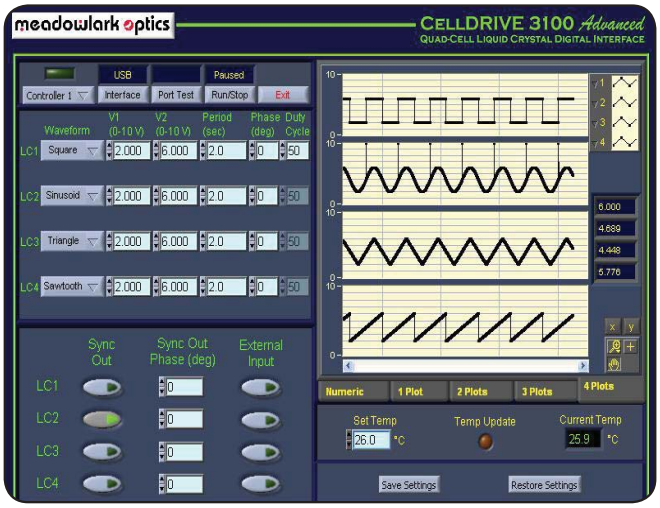


Fig. 5-3 Advanced D3050 operation can accommodate an external modulation signal via a convenient front panel connection

Four Channel Digital Interface

SPECIFICATIONS	
Fundamental Drive Waveform	2 kHz ac square wave
Modulation Amplitude	0-10 V rms
Modulation Resolution	1 mV (0.155 mV using LabVIEW™ subroutines)
DC Offset	< 5 mV
Communications Interface:	USB or RS232
LC Cell to Controller Connections	SMA-SMB, 2 m cable length
Power Requirements	100 – 240 V ac 47 – 63 Hz 500 mA
CE Compliance	compliant
Dimensions (L x W x H)	9.50 x 6.25 x 1.50 in.
Weight	2 lbs.

ADVANCED PACKAGE ONLY	
Modulation Waveforms	external modulation input (0-5 V) sinusoidal triangle square sawtooth transient nematic effect
Temperature Control (one channel only)	Active heating/passive cooling to within ± 1° C of nominal set point
Sync Output	TTL, 1 µs pulse, user specified phase

Minimum System Requirements

- PC with Pentium II class processor
- 32 MB RAM
- CD ROM drive
- 20 MB hard drive space
- USB or RS232 COM Port
- Windows™ 98/ME/2000/XP/Vista
- Use of LabVIEW Instrument Library requires LabVIEW version 6.1 or higher

ORDERING INFORMATION	
Basic	D3040
Advanced	D3050
SMA to SMB Cables	SMA-SMB

Two year and three year extended warranty options available, please contact your Meadowlark Optics sales engineer

Basic package includes:

- **D3040 Controller Unit**
- **User Manual**
- **USB and RS232 cables**
- **Power supply and power cable**
- **CellDRIVE 3000 Basic Software**
- **National Instruments LabVIEW™ virtual instruments driver**

Advanced package includes:

- **D3050 Controller Unit with external input and sync output front panel connectors**
- **User Manual**
- **USB and RS232 cables**
- **Temperature control cable**
- **LC-Controller interface cable**
- **Power supply and power cable**
- **Temperature monitoring and control**
- **CellDRIVE 3100 Advanced Software**
- **National Instruments LabVIEW virtual instruments driver**

NOTES:

1. **D3040 Controllers may be upgraded to D3050 specifications. This upgrade also includes CellDRIVE 3100. Please contact a Sales Engineer for more information.**
2. **Previous generations of Meadowlark LC devices with TSC option may not be compatible with the TSC option in the D3050.**
3. **Previous generations of Meadowlark LC Controllers used BNC to SMB cables. Adapters and replacement cables are available. Please contact a Sales Engineer for assistance.**
4. **Temperature monitoring and control is only available on the D3050 and requires a liquid crystal device with the temperature sensing and control (TSC) option.**

NEW

Two Channel High Voltage Interface

Key Benefits:

- USB or RS232 interface
- C++ code examples (all required libraries included)
- Compact and simple to use
- Microsoft® HyperTerminal configuration file included
- Independent control of voltage levels on two channels to 10 mV resolution
- Includes National Instruments LabVIEW™ Virtual Instrument drivers to interface with custom software

The Two Channel High Voltage Digital Interface is designed for high precision computer control of up to two Meadowlark Optics Swift LC liquid crystal devices at one time.

The D3060HV Package includes all the functionality of the D3050 plus the high voltage circuitry necessary for Swift LC devices. CellDRIVE 3100 HV software includes all the features of the CellDRIVE 3100 Advanced software, but is optimized for the high-speed Swift LC devices. Also included is capability for temperature monitoring and control on one channel. The Advanced Package allows the amplitude of the 13 kHz square wave output to be driven either by an external signal supplied to a front panel connector or specific CellDRIVE generated waveforms including sinusoidal, square, triangle, sawtooth and transient nematic effect waveforms. Additional functions include the capability to output a sync pulse on a front panel connector at desired points in the CellDRIVE generated waveforms and the ability to save/restore all CellDRIVE settings to/from a file.

Package includes:

- D3060HV Controller Unit with external input and sync output front panel connectors
- User Manual
- USB and RS232 cables
- Temperature control cable
- LC-Controller interface cable
- Power supply and power cable
- Temperature monitoring and control
- CellDRIVE 3100 HV Software
- National Instruments LabVIEW virtual instruments driver

SPECIFICATIONS	
Fundamental Drive Waveform	13 kHz ac square wave
Modulation Amplitude	0-100 V rms
Modulation Resolution	10 mV (1.55 mV using LabVIEW™ subroutines)
DC Offset	< 50 mV
Communications Interface	USB or RS232
LC cell to Controller Connections	LEMO™ RF cable, 2 m length
Power Requirements	100 – 240 Vac 47 – 63 Hz 2.5 A
Safety Feature	Keyed Interlock Switch
Dimensions (L x W x H)	10.50 x 7.25 x 4.0 in.
Weight	6 lbs.
Modulation Waveforms	external modulation input (0-5 V) Sinusoidal Triangle Square Sawtooth transient nematic effect
Temperature Control (one channel only)	Active heating/passive cooling to within ± 1° C of nominal set point
Sync Output	TTL, 1 µs pulse, user specified phase

Minimum System Requirements

- PC with Pentium II class processor
- 32 MB RAM
- CD ROM drive
- 20 MB hard drive space
- USB or RS232 COM Port
- Windows™ 98/ME/2000/XP/Vista
- Use of LabVIEW Instrument Library requires LabVIEW version 6.1 or higher

ORDERING INFORMATION	
High Voltage Controller	D3060HV
High Voltage Cable	Swift LC Cable